Simulating Space Weather Extremes: Workshop to assess the preparedness of the US power grid to geomagnetic activity

April 12-14, 2022

Quick Look Report

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Introduction

At 2 a.m. on February 15, the Electric Reliability Council of Texas (ERCOT) declared an Energy Alert Level 3 and utilities began rotating outages due to high consumer demand. The heightened alert was the result of ERCOT officials nervously watching the frequency of the electric power grid drop outside of the narrow 60 hertz band, a number affected by innumerable moving pieces and dynamics from the weather to the operation of the power grid to the user demand on the system.

The events of February 2021 reawakened the world to the precarity of the power grid, a massively complex and integrated system whose resilience in the face of the variability of the natural and human world is anything but guaranteed. The way we see and attempt to control the grid is like trying to know everything about a room we aren't standing in when all we have is a temperature reading from a thermometer within it.

The grid is at the whim of the myriad forces of the natural world and the vicissitudes of human behavior, a truly complex system[1]. Now, as our Sun's cycle ramps back up in activity, we are again being reawakened to a threat to the power grid that has the potential to push the system beyond its tipping point. Space weather is a global and imminent threat, falling in the same likelihood of occurrence in the next five years as “pandemic influenza” on the United Kingdom Risk Registry [*UK Cabinet Office*, 2017], but we are less prepared for a space weather disaster than a pandemic. Progress is precluded by an artificial separation of the relevant disciplines.

To reimagine grid resilience, data from diverse fields must be open and broadly usable and the traditionally disparate communities must be connected.

[1] https://www.youtube.com/watch?v=R4f1NM_a6VU

On April 12-14, 2022 a convergent[2] group crossing the Sun-to-Power Grid system ran a space weather 'simulation game,' a low-risk, cost-effective environment to unite researchers, decision-makers, and operators to assess the preparedness for threats and hazards posed by space weather on the electric power grid.

We have attempted to make this report useful and usable by providing three items: Articulated research and development (R&D) gaps, recommendations based on the R&D gaps, and 'Wishlists' for each link in the information flow in the Sun-To-Power Grid system. Recommendations are provided upfront and R&D gaps and wishlists are provided in the Achievements Section.

The group that gathered included representatives from the National Science Foundation, NASA, Department of Energy, Federal Emergency Management Agency (FEMA), Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), several national space weather programs, and numerous academic and private institutions. A full list of individuals and institutions are provided in Appendix A, noting that a much larger community was engaged in preparing for this event that was not able to attend in person.

The central goal of the workshop was to identify the R&D gaps that arise from a holistic view of the Sun-to-Power Grid system, responding to the question: 'What will affect me that I am not aware of now?' for all members of the Sun-to-Power Grid chain. Auxiliary goals were two fold: **1)** create a community-wide exercise to run models and trace communication lines. This required identifying resource requirements, capability gaps, strengths, areas for improvement, and potential best practices and exploring the communication pathways, data analyses, and responses that an extreme space weather storm triggers and assess the strengths and weaknesses of the research capabilities and operational system; and **2)** cultivate a more cohesive Sun-to-Power Grid community and promote more robust channels of communication among it, including the future technological information systems needed.

Questions that animated us throughout the week and that will continue into the future are:

- What are the research & development and operational gaps that emerge from a **holistic** view of the Sun-to-Power Grid system and what solutions can we imagine to address them?
- What is the composition of the teams that can create these solutions?
- How do we connect these gaps to existing programs and form bridges across them?

This workshop emerged from a paradigm-shifting approach to Sun-to-Power Grid research, development, and operations that occurred through the Convergence Hub for the Exploration of Space Science (CHESS) project. That project adopted a convergence approach, or a radical merging of innovative ideas, approaches, and technologies from a diverse range of sectors and expertise. CHESS created an information flow for the Sun-to-Power Grid System (Figure 1).

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[2] https://www.nsf.gov/od/oia/convergence/index.jsp

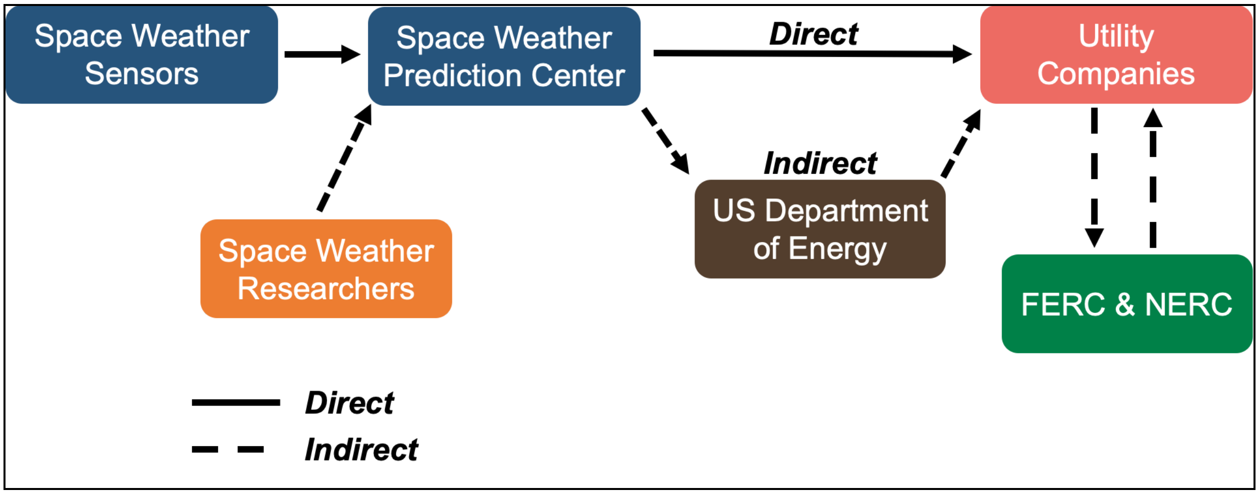

Figure 1: High-level Sun-to-Power Grid Information Flow Diagram defined by the CHESS Project.

The workshop, using the Sim Game Boundary Navigating Object[3][4], improved and enriched that diagram, which organizes and makes actionable the workshop outcomes. The following diagram, created by Alicia Juarrero, will be used to identify intervention points for the Sun-to-Power Grid community, ***for the purpose of improving the resilience of the power grid***.

[3] https://en.wikipedia.org/wiki/Boundary_object

[4] Boundary objects are information that different communities use to coordinate communication, thereby facilitating cross-disciplinary collaboration. Boundary objects are entities that can link communities together as they allow different groups to collaborate on a common task [*Wenger*, 1998]. These 'objects' are typically things with a standardized structure such as forms, maps, and grades [*Lee*, 2007]

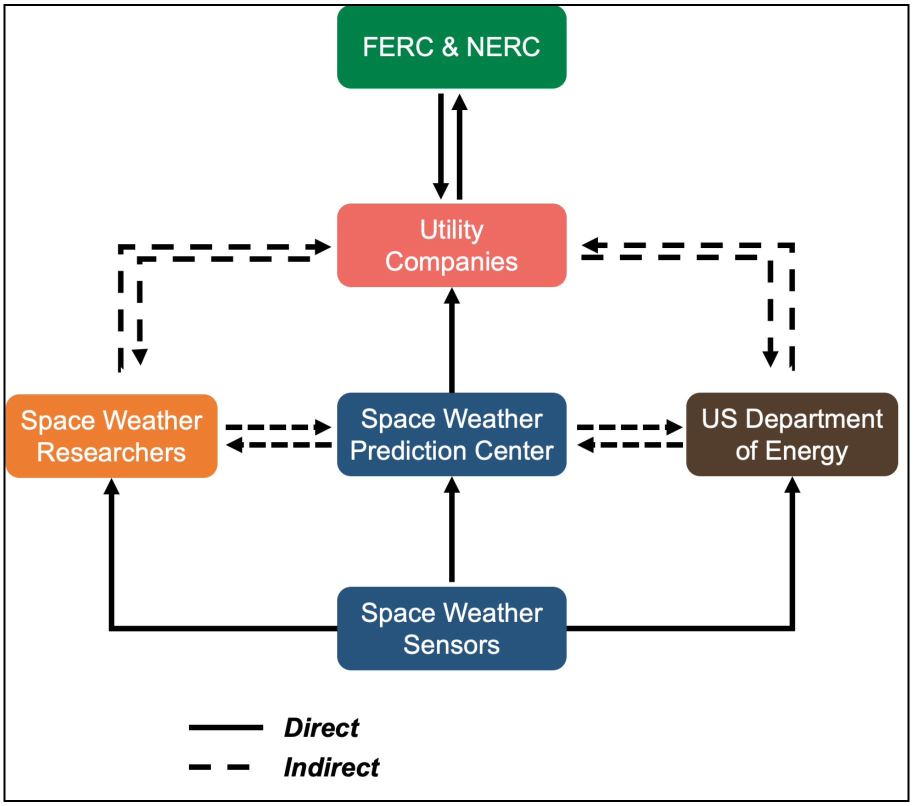

Figure 2: Sun-to-Power Grid Information Flow Diagram (Figure 1) extended by Alicia Juarrero and then iterated upon during the workshop.

This quick-look report provides actionable recommendations. The final report will discuss the design of the event itself and identify the R&D gaps, construct wishlists for each link in the information flow diagram created that will be translation points/handshake items between each entity in the convergent community, and show ways to support sustained conversations among them. Make sure you receive the final report when it is ready by adding your name here: https://forms.gle/4czBo5v9aomCKLdx5

Recommendations

Recommendations are the synthesized guidance for the Sun-to-Power Grid community based on the lessons learned, gaps analysis, and observations across the entire lifecycle of the workshop (proposal, design, convening, conclusion).

- Produce and iterate a 'playbook' for making your research/meetings/conversations more convergent
- Outline for space weather community the hierarchy of power grid roles and responsibility levels (e.g., Reliability Coordinations, Regional Transmission Operators, Utility Managers, Utility Operators) and specify what each level cares about
    - Communicating these ‘levels’ of users to space weather domain would be valuable
    - These levels will not have the same considerations and information needs from the space weather community

    - In general, more training and education for space weather side about power grid needs (there are some FEMA modules being developed that are a good starting point)
    - Develop clear materials for the space weather community to understand power grid domain reporting structure. Start with [Federal Operating Concept for Impending Space Weather Events]
- Have wider space weather community participation in future events, such as the North American Electric Reliability Corporation (NERC) GridEx[5], the largest grid security exercise in North America, and the Electric Power Research (EPRI) Sunburst[6] meetings, as well as power grid community conferences and meetings.
    - Learn from the more mature collaborations, like those with the aviation industry (e.g., how were those relationships developed?).
    - We need to establish a list of the generative questions that space weather and power grid communities can use to interact around
    - Space weather researchers need to be given opportunities to articulate their needs/questions of the power grid.
- In future Research-to-Operations and Operations-to-Research (R2O2R) activities, provide outcomes in the form of a *wishlist*, to provide clear points of interaction between communities.
- Run more simulation games as activities (boundary navigating objects[7]) for these convergent interactions
    - Repetition is key for insight generation and knowledge crystallization
- Have an open space weather contribution to creating software around NERC GIC database[8] that enriches those data and makes them more usable
- Make user exploration a community-wide collaborative effort (better sharing and synthesis across groups, programs, and projects conducting user surveys and interviews)
- Produce a study of the full reliance of power grid functions (beyond just sustaining baseline communications to cover e.g., ability to make bank transactions/payments) on telecommunications
- Incentivize, support, and adopt a complex systems approach to the power grid
- Engage Critical Interdependencies: the interconnectedness of critical infrastructure and society at large require that in future activities the Sun-to-Power Grid community needs to increase the participation of other interdependent organizations, including natural gas utilities, water utilities, and telecom companies/providers/agencies
- Whole-of-power grid coordination: Explore equivalent programs for space weather to the 'Cyber Mutual Assistance (CMA)' for responding to cyber threats to the power grid
- A challenge to convergence (especially for the Sun-to-Power Grid system) is shared vocabulary. It is insufficient and unproductive to attempt to assign one definition to terms,

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[5] https://www.nerc.com/pa/CI/ESISAC/Pages/GridEx.aspx
[6] http://sunburstproject.net/index.html
[7] https://en.wikipedia.org/wiki/Boundary_object
[8] https://www.nerc.com/pa/RAPA/GMD/Pages/GMD-Training.aspx

we need to instead target *glossary harmonization*. These conversations should occur upfront in all convergent meetings, teams, workshops.

- Acknowledge that data and knowledge interoperability is not just within the space weather community, but that wider metadata standards for data provision and description should be utilized. There has been no holistic effort toward glossary harmonization or developing shared vocabulary for the Sun-to-Power Grid.
- Business and population impact needs to factor into the risk calculation and be presented to space weather researchers and power grid engineers. Platforms that can overlay these models on space weather hazards and power grid vulnerabilities are required.
- Identify the science questions that require large-scale integration and computational efforts. This is a way to engage with the Department of Energy through the Advanced Scientific Computing Research
- Create a new space for special publications devoted to research-to-operations (R2O), which is distinct from research manuscripts and operations manuscripts.
- Help mediating groups, like EPRI, become better connected to the research community
- Learn from other geographical regions/countries (e.g., Canada, New Zealand) and from other disciplines (e.g., spacecraft anomaly, Biomedical) about how cross-disciplinary relationships have been developed
- Community coordination requires uncommon approaches, including:
    - Improve our ability to gather and share knowledge across groups larger than 10s of people
    - deeper consideration of how we gather and communicate. It is not enough just to have all these people in the same room and to have a series of presentations. We need multifaceted and multi-level and multiscale forms of communication and connecting
    - Make user exploration a community-wide collaborative effort (better sharing and synthesis)
    - Borrow from the fields of social science, psychology, and team science to improve communication and collaboration. For instance, use of 'boundary navigation objects' like a simulation game